MECHANICAL AND WEAR PROPERTIES OF CARBURIZED MILD STEEL SAMPLES

A thesis submitted in

Partial fulfillment of the requirement for the degree of

MASTER OF TECHNOLOGY

(Mechanical Engineering)

[Specialization: Production Engineering]

BY

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NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

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CERTIFICATE

This is to certify that the thesis entitled, "MECHANICAL AND WEAR PROPERTIES OF CARBURIZED MILD STEEL SAMPLES" submitted by Mr. JAYKANT GUPTA in partial fulfillment of the requirements for the award of *Master of Technology* Degree in *MECHANICAL ENGINEERING* with specialization in *PRODUCTION ENGINEERING* at the National Institute of Technology, Rourkela (deemed University) is an authentic work carried out by him under the joint supervision and guidance of me and Dr. M.kumar.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any degree or diploma.

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JAYKANT GUPTA

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ABSTRACT

The heat treatment and carburization has been acknowledged by some means of improving the various properties of metals and alloys. In the present investigation the mechanical and wear behaviours of mild steels carburized at different temperature range of 850, 900 and 950^{0}C have been studied and it is found that the simple heat treatment greatly improves the hardness, tensile strength and wear resistance of the mild steels. The aim has been to examine the effects of these different carburization temperatures and conditions on the mechanical and wear properties of the carburized mild steels. For above purpose firstly the mild steels are carburized under the different temperature range as stated above and then it is tempered at 200^0 C for half an hour after this the carburized and tempered mild steels are subjected for different kind of test such as abrasive wear test, hardness test, tensile test and the toughness test. The results of these experiment shows that the process of carburization greatly improves the mechanical and wear properties like hardness, tensile strength and wear resistance and these properties increases with increase in the carburization temperature but apart from this the toughness property decreases and it is further decreases with increase in carburization temperature. The experimental results also shows that the mild steels carburized under different temperature range as stated above, with in which the mild steels carburized at the temperature of 950^{0}C gives the best results for the different kinds of mechanical and wear properties because at this temperature it gives highest tensile strength, hardness and wear resistance, so it must be preferred for the required applications.

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CHAPTER 1

INTRODUCTION

1.1 An overview :-

The carburization provides a gradual change in carbon content and carbide volume from the surface to the bulk, resulting in a gradual alteration of mechanical and wear properties. The heat treatment and carburization increases the mechanical and wear resistance. Carburizing is the addition of carbon to the surface of low-carbon steels at temperatures generally between 850 and 950°C (1560 and 1740°F), at which austenite, with its high solubility for carbon, is the stable crystal structure. Hardening is accomplished when the high-carbon surface layer is quenched to form martensite so that a high-carbon martensitic case with good wear and fatigue resistance is superimposed on a tough, low-carbon steel core. Carburizing steels for case hardening usually have base-carbon contents of about 0.2%, with the carbon content of the carburized layer generally being controlled at between 0.8 and 1% C. However, surface carbon is often limited to 0.9% because too high a carbon content can result in retained austenite and brittle martensite.

Carburizing is one of the most widely used surface hardening processes. The process involves diffusing carbon into a low carbon steel alloy to form a high carbon steel surface. Carburizing steel is widely used as a material of automobiles, form implements, machines, gears, springs and high strength wires etc. which are required to have the excellent strength, toughness, hardness and wear resistance, etc.because these parts are generally subjected to high load and impact. Such mechanical properties and wear resistance can be obtained from the carburization and quenching processes. This manufacturing process can be characterized by the key points such as: it is applied to low carbon workpieces, workpieces are in contact with high carbon gas, liquid or solid, it produces hard workpiece surface, workpiece cores retain soft.

1.2 Need of present work :-

Agriculture is the backbone of economy for most of the developing nations including India and a source of income for more than 60% of their population. In spite of the fact that the mechanization of agriculture helps in reducing human drudgery and raising grain productivity, the level of mechanization in these countries is still at very low level. The main reason for this is non-availability of high quality implements and lack of demonstrated services for their populization. Mechanization does not mean only the agro-machines operated by power, but also the implements run by animals and men. Most commonly used farm implements are ploughs, harrows, cultivators, peddlers, furro opener, khurpy, kudali, etc. Indian agro industries and village artisans usually use cheaply and abundantly available low carbon and mild steels for the manufacture of these farm implements to suit every farmer, either rich or poor.

During agricultural operations (either dry or wet) the farm implements undergo abrasion by the scratching actions of sand and stone particles present in the soil and it is the most common cause of their quick failure and damage. It is therefore necessary to minimize wear. Due to limited resources and unavailability of economically feasible technology, agro industries have not been able to substantially improve the mechanical properties and wear resistance of these steels. The attempt have been made by researchers to improve the wear resistance of steel materials, but very little attention has been paid in reducing the wear of farm implements materials. Thus, there is an urgent need to substantially upgrade the mechanical properties and wear resistance of low carbon and mild steels in actual soil conditions.

The present work aims to improve the wear resistance and mechanical properties of mild steel by developing an economically feasible carburization technique. Also the present work is applicable not only for the farm implements but also for the applications like material of automobiles, machines, gears, springs and high strength wires etc.

1.3 Ferrous materials :-

The word “ferrous” usually refers to the materials that have a lot of iron in them. It is common for these materials to be strongly magnetic but not all of them are. Different type of iron and steel are more or less magnetic. High-chromium stainless steel is nearly non-magnetic, while pure iron tends to form magnets easily. Iron with impurities usually stays magnetic better than pure iron.

These ferrous materials are mainly classified in the two different types.

1. Steels: - Carbon contain up to 2%

a. Plain carbon steel

b. Alloy steel

2. Cast iron: - Carbon contain above 2% to 6.67%

a. Grey cast iron

b. White cast iron

c. Malleable cast iron

d. Ductile cast iron

1.4 Plain carbon steels :-

The plain steels are generally classified in following 3 types.

1. **Low carbon steel: -** up to 0.30% of carbon.

Mild steel is the most common form of steel as its price is relatively low while it provides material properties that are acceptable for many applications. Low carbon steel contains approximately 0.05–0.15% carbon and mild steel contains 0.16–0.30%- carbon . Mild steel has a relatively low tensile strength, but it is cheap and malleable; surface hardness can be increased through carburizing. It is used where ductility or softness are important.

Properties: Malleable and ductile, and therefore bends fairly easily

Uses: - It is used for nut, bolts, screws, automobile body panels, tin plate, wire product, tubes, girders etc.

2. **Medium carbon steel**: - From 0.30 to 0.60% of carbon.

These are less ductile but harder and have greater tensile strength than low carbon steel. It balances ductility and strength and has good wear resistance. They have also better machining qualities.

Properties: Harder, better tensile strength, good wear resistance.

Uses: - Shafts, connecting rods, spindles, gears, crank shaft, couplings, rail wheels, rail axle etc.

3. **High carbon steel**:- From 0.60 to 1.70% of carbon

They have higher tensile strength and harder than other plain carbon steels. They also readily respond to heat treatment. These steels can be tempered to great hardness. Used for special purposes like (non-industrial-purpose) knives, axles or punches. Most of these steels with more than 1.2% carbon content are made using powder metallurgy.

Properties: Tough rather than hard, and fairly ductile

Uses :- Used for making hand tools such as wrenches, chisels, punches, files, cutting tools such as drills, wood working tools, rail road wheels, springs, high strength wires etc.

1.5 Case hardening :-

Case hardening is a simple method of hardening steel. This techniques is used for steels with a low carbon content. Carbon is added to the outer surface of the steel, to a depth of approximately 0.03mm. This hardening process includes a wide variety of techniques is used to improve the mechanical properties and wear resistance of parts without affecting the softer, tough interior of the part. This combination of hard surface and resistance and breakage upon impact is useful in parts such as a cam or ring gear that must have a very hard surface to resist wear, along with a tough interior to resist the impact that occurs during operation. Further, the surface hardening of steels has an advantage over through hardening because less expensive low-carbon and medium-carbon steels can be surface hardened without the problems of distortion and cracking associated with the through hardening of thick sections. One advantage of this method of hardening steel is that the inner core is left untouched and so still processes properties such as flexibility and is still relatively soft.

1.6 Types of case hardening :-

The case hardening of steels is generally categorized into the two different types.

1.Steel with carbon content less than 0.25%

For this kind of case hardening the chemistry of the surface needs to be change by adding carbon and nitrogen to get hard martensite. This category of treatment is known as chemical heat treatment techniqe and involves carburizing, nitriding, carbonitriding and cyaniding.

Examples:- Carburizing, nitriding, carbonitriding, cyaniding

2.Steel with carbon content more than 0.35%

For this kind of steel the surface can be hardened by flame, induction and laser hardening techniques.

Examples :- Flame hardening, induction hardening, laser hardening

1.6.1 Carburization:-

Carburization is simply defined as the addition of carbon to the surface of low carbon steel at temperature generally between 850-950 degree Celsius.

Carburization is the most widely used method of surface hardening. It consist of enrichment of surface layers of low carbon / mild steel (c less than equal to 0.30%) with carbon up to 0.8 % to 1% by this way the good wear and fatigue resistance is superimposed on a tough low carbon steel core. usually have base-carbon contents of about 0.2%, with the carbon content of the carburized layer generally being controlled at between 0.8 and 1% **C**. However, surface carbon is often limited to 0.9% because too high a carbon content can result in retained austenite and brittle martensite.

FIG.1:- Microstructure of the sample just at the bottom of the pit. The brown area is pearlite and represent an area of carbon pickup from the coke.

1.6.2 Types of carburization:-

There are following types of carburization processes exist

1. Solid carburization
2. Gaseous carburization
3. Vacuum carburization
4. Plasma carburization
5. Salt bath carburization

1. **Solid carburization:-**

The solid or pack carburization involves heating the steels parts embedded in powdery mixture of 85% coal and 15% BaCO3 at a temperature in range 900-950 degree Celsius. The residual air in the box combines with carbon to produce Co gas. Carbon monoxide gas is unstable at the process temperature and thus decomposes upon contacting the iron surface by reaction.

$$2CO = C + CO_2$$

The atomic carbon enters the steel through the following reaction.

$$Fe+2CO = Fe(C) + CO_2$$

The addition of $BaCO_3$ enhances the carburizing effect. $BaCO_3$ decomposes and evolves

CO_2 which react with coal to form carbon monoxide.

$$C+CO_2 = 2CO$$

solid carburization is a time consuming procedure. Typical carburizing time to obtain a case depth of 1-2 mm is around 6-8 hours. Higher speed can be obtained by carburizing in gaseous medium.

2. **Gaseous carburization:-**

The gaseous carburization is carried out at temperature in range 900-950 degree Celsius. Carbon monoxide and various hydrocarbon are used as a carburizers. They decompose at the process temperature and form atomic carbon according to the following reaction.

$$2CO = C + CO_2$$

$$C_n + H_m = nC + mH$$

It is very essential to accurately control the composition and flow rate of carburizing gas. Gas carburization is the main process in mass production, while the simpler solid carburization is economically more effective in small scale production.

3. **Vacuum carburization:-**

In efforts required to simplify the atmosphere, carburizing in an oxygen-free environment at very low pressure (vacuum carburizing) has been explored and developed into a viable and important alternative. Although the furnace enclosure in some respects becomes more complex, the atmosphere is greatly simplified. A single-component atmosphere consisting solely of a simple gaseous hydrocarbon, for example methane, may be used. Furthermore, because the parts are heated in an oxygen-free environment, the carburizing temperature may be increased substantially without the risk of surface or grain-boundary oxidation. The higher temperature permitted increases not only the solid solubility of carbon in the austenite but also its rate of diffusion, so that the time required to achieve the case depth desired is reduced.

Although vacuum carburizing overcomes some of the complexities of gas carburizing, it introduces a serious new problem that must be addressed. Because vacuum carburizing is conducted at very low pressures, and the rate of flow of the carburizing gas into the furnace is very low, the carbon potential of the gas in deep recesses and blind holes is quickly depleted. Unless this gas is replenished, a great non uniformity in case depth over the surface of the part is likely to occur.

4. **Plasma and salt bath carburization:-**

A method that overcomes both of these major problems yet retains the desirable features of a simple atmosphere and permissible operating temperature is plasma or ion carburizing.

These methods introduce carbon by the use of gas (atmospheric-gas, plasma, and vacuum carburizing), liquids (salt bath carburizing), or solid compounds (pack carburizing). All of these methods have limitations and advantages, but gas carburizing is used most often for large-scale production because it can be accurately controlled and involves a minimum of special handling.

Vacuum carburizing and plasma carburizing have found applications because of the absence of oxygen in the furnace atmosphere. Salt bath and pack carburizing arc still done occasionally, but have little commercial importance today.

1.6.3 Nitriding :-

Nitriding is a surface-hardening heat treatment that introduces nitrogen into the surface of steel at a temperature range (500 to 600°C) while it is in the ferrite condition. Thus, nitriding is similar to carburizing in that surface composition is altered, but different in that nitrogen is added into ferrite instead of austenite. Because nitriding does not involve heating into the austenite phase field and a subsequent quench to form martensite, nitriding can be accomplished with a minimum of distortion and with excellent dimensional control. In this process pure ammonia dissociates by the reaction

$$NH_3 = 3H + N$$

The atomic nitrogen thus formed diffuses into the steel. In addition to providing outstanding wear resistance , the nitride layer increases the corrosion resistance of steel in moist atmosphere. Practically only alloy steels are subjected to nitriding.

1.6.4 Carbonitriding and cyaniding :-

Carbonitriding is a modified form of gas carburizing, at a temperature range between 750 - 900^0 C.The modification consists of introducing ammonia into the gas carburizing atmosphere to add nitrogen to the carburized case as it is being produced. Nascent nitrogen forms at the work surface by the dissociation of ammonia in the furnace atmosphere; the nitrogen diffuses into the steel simultaneously with carbon. Typically, carbonitriding is carried out at a lower temperature and for a shorter time than is gas carburizing, producing a shallower case than is usual in production carburizing.

In its effects on steel, carbonitriding is similar to liquid cyaniding. Because of problems in disposing of cyanide-bearing wastes, carbonitriding is often preferred over liquid cyaniding. In terms of case characteristics, carbonitriding differs from carburizing and nitriding in that carburized cases normally do not contain nitrogen, and nitrided cases contain nitrogen primarily, whereas carbonitrided cases contain both.

1.6.5 Flame hardening :-

This is the simplest form of heat treatment process. The workpiece is heated by means of a gas torch (oxy-acetylene flame) followed by a water spray on the heated parts. The heat from the torch penetrates only to small depth on the surface and consequently the steel in the outer layers gets quenched to martensite and bainite. Case depth up to 3mm can be achieved by this process. This process can be followed by heating to about 200 ^{0} C for the purpose of stress relieving. The surface hardness is not appreciably affected by these reheating operations. This process is suitable for any complex shape of component such as crank shaft, large gears, cam, etc. with carbon percentage ranging from 0.3 to 0.6%. Though high carbon steel can also be flame hardened, greater care is needed to avoid surface cracking.

1.6.6 Induction hardening :-

This is similar to flame hardening process where the heating of component surface is achieved by the electromagnetic induction. The workpiece such as crank shaft is enclosed in the magnetic field of an alternating (10 kHz to 2MHz) current conductor to obtain case depth of the order of 0.25 to 1.5 mm. This causes induction heating of the workpiece, The heated workpiece then quenched by water spray. The induction heat penetrates only outer surface of the workpiece as a result only the skin gets hardened by the quenching process. The whole process is very fast (5s to 4 minutes) and result in hard outer surface (50 to 60 R_c) which is wear resistant.

1.7 Tempering:-

After the hardening treatment is applied, steel is often harder than needed and is too brittle for most practical uses. Also, severe internal stresses are set up during the rapid cooling from the hardening temperature. To relieve the internal stresses and reduce brittleness, you should temper the steel after it is hardened. Tempering consists of heating the steel to a specific temperature (below its hardening temperature), holding it at that temperature for the required length of time, and then cooling it, usually instill air. The resultant strength, hardness, and ductility depend on the temperature to which the steel is heated during the tempering process.

The purpose of tempering is to reduce the brittleness imparted by hardening and to produce definite physical properties within the steel. Tempering always follows, never precedes, the hardening operation. Besides reducing brittleness, tempering softens the steel. That is un-avoidable, and the amount of hardness that is lost depends on the temperature that the steel is heated to during the tempering process. That is true of all steels except high-speed steel. Tempering increases the hardness of high-speed steel. Tempering is always conducted at temperatures below the low-critical point of the steel. Normally, the rate of cooling from the tempering temperature has no effect on the steel. Steel parts are usually cooled in still air after being removed from the tempering furnace.

1.7.1 Why tempering of steel needed:-

After the hardening treatment is applied, steel is often harder than needed and is too brittle for most practical uses. Also, severe internal stresses are set up during the rapid cooling from the hardening temperature. To relieve the internal stresses and reduce brittleness, you should temper the steel after it is hardened. So the main purpose of tempering is to reduce the brittleness imparted by hardening and to produce definite physical properties within the steel.

1.8 Wear of material:-

Wear is commonly defined as the undesirable deterioration of a component by the removal of material from its surface. It occurs by displacement and detachment of particles from surface. The mechanical properties of steel are sharply reduced due to wear. The wear of material may be due to the friction of metals against each other, eroding effect of liquid and gaseous media, scratching of solid particles from the surface and other surface phenomena. In laboratory tests, wear are usually determined by weight loss in a material and wear resistance is characterized by the loss in weight per unit area per unit time. There are following principle types of wear as described below.

1.8.1 Abrasive wear: - It results when non metallic particles penetrate the metal surface and cause removal of metallic debris. Abrasive wear is a dominant failure mechanism of engineering components. The abrasive wear resistance in general increases with increase in hardness.

1.8.2 Adhesive wear or metal to metal wear: - This wear caused due to relatives sliding or rolling movement of two mating metallic surfaces. If contact pressure are high it cause to permanent plastic deformation of rubbing component.

1.8 3 Erosive wear: - Erosive wear occur as a result of relative movement between metal and liquid or gas.

1.8.4. Corrosive wear: - The destruction of materials by the action of surrounding medium is called corrosion. Corrosive wear begins at the surface and gradually penetrates into the matrix.

1.8.5. Fatigue wear: - The removal of particles by cyclic processes comes under the category of fatigue wear. This type of wear predominates in most practical machine component.

1.8.6 Factors affecting wear of metallic materials:-

The wear rate can be influenced by a number of factors as given below:-

1. Physico chemical properties of materials, such as composition, microstructure, hardness, work hardening characteristics, corrosion resistance, wear strength, etc.

2. Wear conditions such as contact areas, load applied, temperature, presence of lubricants, degree of lubrication, rotational/sliding speed, flow rate of liquid or gas, nature of environment, duration of wear etc.

3. Characteristics of abrasive involving hardness, shape and size.

4. Design properties involving transmission of load, type of motion, test geometry etc.

1.9 Mechanical properties:-

Strength, hardness, toughness, elasticity, plasticity, brittleness, and ductility and malleability are mechanical properties used as measurements of how metals behave under a load. These properties are described in terms of the types of force or stress that the metal must withstand and how these are resisted.

1.9.1 Strength:-

Strength is the property that enables a metal to resist deformation under load. The ultimate strength is the maximum strain a material can withstand. Tensile strength is a measurement of the resistance to being pulled apart when placed in a tension load.

Fatigue strength is the ability of material to resist various kinds of rapidly changing stresses and is expressed by the magnitude of alternating stress for a specified number of cycles.

Impact strength is the ability of a metal to resist suddenly applied loads.

1.9.2 Hardness:-

Hardness is the property of a material to resist permanent indentation. Because there are several methods of measuring hardness, the hardness of a material is always specified in terms of the particular test that was used to measure this property. Rockwell, Vickers, or Brinell are some of the methods of testing. Of these tests, Rockwell is the one most frequently used. The basic principle used in the Rockwell testis that a hard material can penetrate a softer one. We then measure the amount of penetration and compare it to a scale. For ferrous metals, which are usually harder than nonferrous metals, a diamond tip is used.

1.9.3 Toughness:-

Toughness is the property that enables a material to withstand shock and to be deformed without rupturing. Toughness may be considered as a combination of strength and plasticity.

1.9.4 Elasticity:-

When a material has a load applied to it, the load causes the material to deform. Elasticity is the ability of a material to return to its original shape after the load is removed. Theoretically, the elastic limit of a material is the limit to which a material can be loaded and still recover its original shape after the load is removed.

1.9.5 Plasticity:-

Plasticity is the ability of a material to deform permanently without breaking or rupturing. This property is the opposite of strength. By careful alloying of metals, the combination of plasticity and strength is used to manufacture large structural members. For example, should a member of a bridge structure become overloaded, plasticity allows the overloaded member to flow allowing the distribution of the load to other parts of the bridge structure

1.9.6 Brittleness:-

Brittleness is the opposite of the property of plasticity. A brittle metal is one that breaks or shatters before it deforms. White cast iron and glass are good examples of brittle material. Generally, brittle metals are high in compressive strength but low in tensile strength. As an example, you would not choose cast iron for fabricating support beams in a bridge

1.9.7 Ductility and malleability:-

Ductility is the property that enables a material to stretch, bend, or twist without cracking or breaking. This property makes it possible for a material to be drawn out into a thin wire. In comparison, malleability is the property that enables a material to deform by compressive forces without developing defects. A malleable material is one that can be stamped, hammered, forged, pressed, or rolled into thin sheets.

1.10 Objectives of the present work:-

The aim of present work is to improve the mechanical properties and wear resistance of the mild steels by using vasundhara coal as a carburizer and less energy consuming carburization technique. In this connection the following studies were aimed to be carried out.

1. Proximate analysis of the vasundhara coal.
2. Carburization of mild steel samples under various conditions and various temperatures by using less energy consuming techniques.
3. Tempering of these carburized mild steel samples at a definite temperature for a particular period of time.
4. Determination of mechanical properties like hardness, toughness and tensile strength of these carburized and tempered mild steel samples.
5. Study of abrasive wear characteristics of these carburized and tempered mild steel samples.
6. Analysis of the results obtained.

1.10.1 Mechanical and wear properties studied:-

The following mechanical and wear properties were studied and analyzed in the present work.

1. **Abrasive wear**
2. **Toughness**
3. **Tensile strength**
4. **Hardness**

During these work the effects of following parameters on mechanical properties and wear characteristics of carburized and tempered mild steel samples were examined.

1. Carburization temperature and soak time.
2. Quality of carburizer.
3. Tempering temperature and time.
4. Carbon content in the parent steel.

CHAPTER 2

LITERATURE REVIEW

The investigation on the mechanical and wear properties of iron and steel component under different condition have been made by a number of workers. Most of these investigation had been made on analysis of wear properties a very few studies were made including both the mechanical and wear properties under the same parameters and conditions.

Luo et al [10] studied the effects of microstructure on the abrasive wear behavior of spheroidal cast iron and reported that the wear resistance of spheroidal grey cast iron was inferior to that of steel with a similar matrix. Quenched structures were more resistant to abrasion than the austempered structures. In addition, the wear performance of quenched iron and steel samples were reported to be better than austenized at higher temperature.

Celik et al [7] studied the high temperature abrasive wear behavior of an as-cast ductile iron and reported that the high temperature tensile properties were affected by dynamic strain aging. Serrated flow was observed in the temperature range between 100 and 300 ◦C. In this temperature regime, tensile strength values were almost invariable. Above 400 ◦C, increase of temperature decreased the tensile strength. Minimum ductility was observed at 500 ◦C. At 600 ◦C, higher ductility was observed than that of 500 ◦C. he also concluded that after the increase in wear resistance at 50–100 ◦C, abrasive wear resistance decreased with increasing temperature. Dynamic strain aging caused improvement of abrasion resistance. The highest resistance to abrasive wear is observed at temperature range between 50 and 100 ◦C. At this temperature range ductile iron exhibited more than 15% higher abrasion resistance than room temperature.

Izciler and Tabur [8] on his study of abrasive wear behavior of different case depth gas carburized AISI 8620 gear steel concluded that in respect with microstructures, samples subjected to longer periods of gas carburizing exhibit greater case depth The samples having greater case depth and surface hardness are more wear resistant than that with low case depth. The hardness of the abrasives in relation with the applied loads and wear distances had affected the wear resistance significantly. Comparing Al2O3 and SiC abrasive papers, Al2O3 abrasive papers loose their sharpness more than SiC papers do, especially under higher loads.

Khusid et al [9] on his work studied the Wear of carburized high chromium steels and reported that Carburization raises the abrasive wear resistance and allows significant suppression of the adhesion phenomena under dry sliding. The results obtained determine the regime of surface hardening of high chromium steels required to produce the desired combination of wear resistance and bulk strength properties.

The results of an experimental investigation carried out by **Akdemir** et al [11] on Impact toughness and microstructure of continuous steel wire-reinforced cast iron composite and reported that absorbed energy of the gray cast iron increases basically with adding the ductile reinforcement. Also absorbed energy of the composite decreases with decreasing test temperature since the steel wire in the composite looses its ductility and behaves as a brittle material as the test temperature was decreased. He also reported that Impact toughness of the gray cast iron was not improved with the increasing normalization temperature since there is no change in the morphology of graphite flakes in the gray cast iron with normalizing heat treatment. Normalizing heat treatment does not affect impact toughness of the cast composite significantly, because the partially dissolved region is very narrow due to insufficient volume fraction for the current work condition.

Baldissera and Delprete [12] studied effects of deep cryogenic treatment (DCT) on static mechanical properties of 18NiCrMo5 carburized steel and concluded that The soaking time parameter shows a strong influence on the hardness increase induced by the pre-tempering DCT and, under the assumption that the microstructural mechanism involves the entire process further improvements could be possible with a prolonged DCT exposure. The unchanged tensile strength of the pre-tempering DCT groups could be related to a compensation effects due to the loss in residual stress, as it is reported by literature.

Kayali et al [13] on his work of high Temperature Tensile and Abrasive Wear Characteristics of As-cast Ductile Irons reported that At entire temperature range pearlitic ductile iron exhibited higher strength and lower ductility than ferritic ductile iron. High temperature tensile testing caused serrated flow in the temperature range between 100 and 300°C. In this temperature regime, tensile strength values of both ductile irons were almost invariable. Above 400°C, increase of temperature decreased both tensile strength and ductility dramatically. However, ferritic ductile iron exhibited significantly higher ductility at 600 than 500°C.

Wang and Lei [17] observed that wear resistance increased in following order: spherodized carbide, martensite, bainite and lamellar pearlite. The result also indicated that the difference in wear resistance of various microstructures were caused by the differences in their thermal stability, resistance to deformation, resistance to nucleation and propagation of micro-cracks etc.

In series of experiments, **Kumar and Gupta** [14, 15] carried out extensive studies on low stress abrasive wear characteristics of carburized mild steels, and heat tested medium carbon and alloy steels. The authors found that the hardness and abrasion resistance of carburized mild steels increased considerably with increase of carburization temperature and soak time; use of coaltar pitch and quenching oil on mild steel surface and its subsequent carburization in charcoal greatly Improved the wear resistance of carburized mild steel; the highest abrasion resistance was observed in the steel samples carburized in partially burnt charcoal and the hardness and wear resistance values of mild steels carburized by using coaltar pitch were comparable with those of heat treated high carbon low Cr steels.

Bepari et al [16] studied the effects of Cr and Ni addition on the structure and properties of carburized low carbon steels and found that both Cr and Ni promote the formation of retained austenite in carburized and hardened steel, Cr being more effective. Both were found to refine the martensite platelets, with Ni being more effective the hardenability was found to increase with increase of autenite grain size and with extent of carbon penetration in carburized steel.

CHAPTER 3

EXPERIMETAL DETAILS

(Materials and Methods)

3.1 Materials Selection:-

Mild steels of the required dimensions were purchased from the local market and the test specimens were prepared from it. The chemical composition of mild steel by (wt %) is given as follows C-0.16, Si-0.03, Mn-0.32, S-0.05, P-0.2, Ni- 0.01, Cu-0.01, Cr-0.01 and Fe.

3.2 Preparation of test specimens:-

The test specimen for analysis of different mechanical and wear properties like abrasive wear, toughness, tensile strength and hardness were prepared as per ASTM standard and its description is given below.

1. **Specimen for abrasive wear and hardness test:-** The abrasive wear and hardness is determined from the same specimen. A standard specimen of dimensions (4cm x 2.5cm x 0.5cm) of mild steel is prepared for the same purpose.

Fig. 2 Specimen for abrasive wear and hardness test

2. **Specimen for toughness test:-** A toughness test specimen as per ASTM standard is prepared for the same purpose having the following dimensions.

   Length – 5.5 cm

   Width – 1 cm

   Thickness – 1 cm

   Notch depth – 0.5 cm

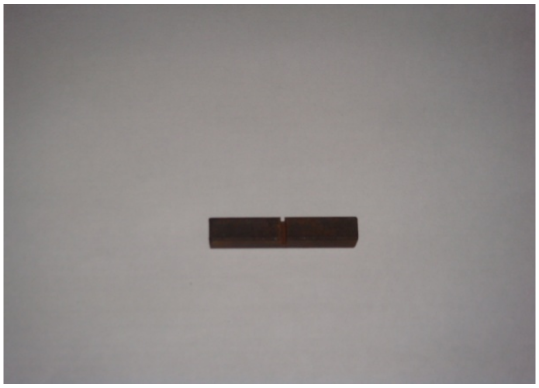
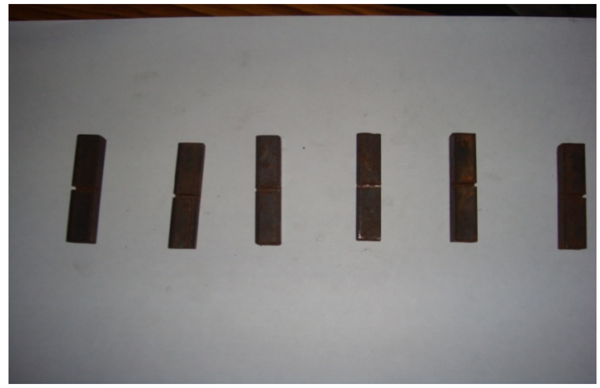

Fig. 3 specimen for toughness test

3. **Specimen for tensile strength test:-** A tensile test specimen as per ASTM standard is prepared for this purpose is based on the following equation.

$$L_0 = 5.65\sqrt{A_0}$$

Where, L_0 = Gauge length

A_0 = Cross sectional area


Fig. 4 Specimen for tensile strength test

3.3 Coal selection and preparation:- The vasundhara coal is taken for this purpose and it is crushed into -52 mesh size with the help of crusher and test sieve, about 4 kg of coal is prepared for this purpose and this coal is used for the pack carburization of mild steel samples.

3.4 Proximate analysis of vasundhara coal:-

Analysis for moisture, volatile matter, ash and fixed carbon contents in vasundhara coal (Table) were carried out on Samples ground to pass through -72 mess B.S. test sieve by the method given below.

3.4.1 Moisture determination:-

One gram of air dried coal powdered sample of size -72mess was taken in a borosil glass crucible and then kept in the air oven maintained at the temperature 110°C.The sample was soaked at this temperature for one hour and then taken out from the furnace and cooled. Weight loss was recorded using an electronic balance. The percentage loss in weight gave the percentage moisture content in the sample.

3.4.2 Volatile matter determination:-

One gram of air dried coal powdered sample of size -72 mess was taken in a volatile matter crucible (made of silica) and kept in the muffle furnace maintained at the required temperature of 925°C.The sample was soaked at this temperature for seven minutes and then crucible was taken Out from the furnace and cooled in air. Weight loss in the sample was recorded by using an electronic balance. The percentage loss in weight – moisture present in the sample gives the volatile matter content in the sample.

3.4.3 Ash determination:-

One gram of air dried powdered sample of size -72mess was taken in a shallow silica disc and kept in the muffle furnace maintained at the temperature of 775-800°C.The sample was kept in the furnace till complete burning. Weight of ash formed was noted down and the percentage ash content in the sample was determined.

3.4.4 Fixed carbon determination:-

The fixed carbon content in the sample was determined by using the following formula:

Fixed Carbon Content (Wt. %) =100 - Wt %(Moisture +Volatile matter + Ash)

3.5 Carburization of mild steel samples:-

The different test specimen samples made up of mild steel for mechanical and wear properties testing were subjected to pack carburization treatment. In this process the mild steel samples were placed on the thick bed of carburizer kept in a stainless steel container and fully covered from all sides, the top of the container was covered with a steel plate. The container was then introduced into the muffle furnace and then maintained at the different required carburization temperatures of 850, 900 and 950^{0}C with the soak time of 2 hours by this way the mild steel samples gets carburized and then they were quenched in water i.e. the hardening was effected immediately after carburization. By this carburization process the mechanical and wear properties of mild steel samples increased considerably. The carburized steel samples were then tempered for a particular temperature and time and then it processed for the different type of mechanical and wear test.

Fig. 5 Muffle furnace for carburization of mild steel samples

3.6 Tempering of carburized mild steel samples:-

After the carburization process, the steel is often harder than needed and is too brittle for most practical uses. Also, severe internal stresses are set up during the rapid cooling from the hardening temperature. To relieve the internal stresses and reduce brittleness, we should temper the steel after it is hardened. So in this tempering process the carburized steel samples were heated at the temperature of 200^{0}C for duration of 0.5 hours and then cooling it usually in the still air. The carburized and tempered mild steel specimens are then subjected to various kind of mechanical and wear test.

3.7 Abrasive wear test:-

The materials considered for this experiment is carburized mild steel samples which is carburized under different temperature range of 850, 900 and 950^{0}C with dimensions 4.0cm x 2.5 cm x 0.5 cm. The test was conducted on a machine called Pin on disc machine (make: SD scientific industries) as shown in fig. The sample was mounted perpendicularly on a stationary vice such that its one of the face is forced to press against the abrasive that is fixed on the revolving disc. Hence it is the abrasive paper that tends to wear the surface of the samples. When the disc rotates for a particular period of time, the sample can loaded at the top to press against the disc with the help of a lever mechanism.

In this experiment the test can be conducted with the following parameters

(1) Load (2) Speed (3) Time

In the present experimental work, speed and time wear kept constant while the load was varied from 14.7 N to 49 N. Parameters that remained constant through out all the experiments are given in table ( ).

RPM	300
Time	5 minute
Type of abrasive paper	Emery, 80 grade size

Table 1 Parameter taken constant in abrasive wear test

For each of the sample, test was conducted for 5 times and the average of all the samples was taken as the observed values in each case.

Once the parameter is set and work piece is mounted, the test is carried on for the desired time. The wear track so formed on the rotating disc is a circle. After each test only the mass loss of the specimen was considered as the wear.

The wear rate of each sample was calculated from the weight loss, the amount of wear is determined by weighing the specimen before and after the test using precession electronic weighing machine. Since the mass loss is measured it is converted to volume loss using the density of the specimen. Hence wear volume, wear rate and wear resistance can be calculated as follows.

1. **wear volume:-**

   Wear volume = weight loss / density

   Density of specimen = 7.86 g /cm^3

2. **wear rate:-** It is defined as wear volume per unit distance travelled

   Wear rate =wear volume / sliding distance(s)

   Sliding distance (s) can be calculated as

   Sliding distance (s) = V x time

   = (2 π R N / 60) x time

   Where, R = radius of abrasive wheel (7.25cm)

   N = R.P.M (300)

   Π = 3.14 (constant)

   Time = 5 minute = 300 S

3. **wear resistance:-** wear resistance is a reciprocal of wear rate

   wear resistance = 1 / wear rate

Fig. 6 Pin on disc machine for abrasive wear testing.

3.8 Hardness test:-

Rockwell hardness testing is a general method for measuring the bulk hardness of metallic and polymer materials. Although hardness testing does not give a direct measurement of any performance properties, hardness correlates with strength, wear resistance, and other properties. Hardness testing is widely used for material evaluation due to its simplicity and low cost relative to direct measurement of many properties.

This method consists of indenting the test material with a diamond cone or hardened steel ball indenter. The indenter is forced into the test material under a preliminary minor load *F0* usually 150kg. When equilibrium has been reached, an indicating device, which follows the movements of the indenter and so responds to changes in depth of penetration of the indenter, is set to a datum position. While the preliminary minor load is still applied an additional major load is applied with resulting increase in penetration. When equilibrium has again been reach, the additional major load is removed but the preliminary minor load is still maintained. Removal of the additional major load allows a partial recovery, so reducing the depth of penetration. The permanent increase in depth of penetration, resulting from the application and removal of the additional major load is used to calculate the Rockwell hardness number.

In present experimental work Rockwell hardness was measured on carburized and tempered mild steel samples which are carburized under different temperature range of 850, 900 and 950^0C. For each of the sample, test was conducted for 5 times and the average of all the samples was taken as the observed values in each case.

Fig. 7 Rockwell hardness tester

3.9 Tensile test:-

The tensile strength is measured by tensile test which is carried out on an Instron 1195 machine. This involves the preparation of a test specimen as per ASTM standard as shown in fig.4 and this test specimen is based on following relation.

$$L_0 = 5.65\sqrt{A_0}$$

Where, L_0 = Gauge length

A_0 = Cross sectional area

Here the important parameter are the gauge length L_0 and the cross sectional area A_0 then a uniformly increasing load is applied on the specimen. As the load increases the specimen initially gets elastically elongated. On further elongation, the specimen starts necking at some points when the material goes beyond the elastic range. The reduced width of specimen would further be reduced under the force of the load and finally develops fractures when the test is completed

It can be observed that there is a limit up to which the applied stress is directly proportional to the induced strain, the end of this linear portion is the yield point of the material above which the material starts plastically deforming and when the force applied load goes beyond the limit that can borne by the material, the specimen breaks. The stress at elastic limit is called yield strength. The maximum stress reached in a material before the fracture is termed as the ultimate tensile strength.

In present experiment the tensile test was carried out on carburized and tempered mild steel samples which are treated under different temperature range of 850, 900 and 950^{0}C and the following condition were taken during tensile test in Instron 1195 machine.

3.9.1 Machine parameter of Instron 1195 tensile test:

Sample type	:	ASTM
Sample rate (pts/sec)	:	9.103
Cross head speed (mm/min)	:	2.000
Full scale loading range (KN)	:	50.00
Humidity (%)	:	50
Temperature (^{0}F)	:	73

3.9.2 Dimensions parameters of specimen for Instron 1195 tensile test:-

Width	-	7 mm
Thickness	-	5 mm
Gauge length	-	34 mm
Grip distance	-	100 mm

Fig. 8 Instron 1195 machine for tensile test

3.10 Toughness (Charpy impact) test:-

The test is conducted for the three different samples carburized under the three different temperatures of 850, 900 and 950^{0}C. The test consist of measuring the energy absorbed in breaking a ASTM standard U – notched specimen by giving a single blow by swinging hammer. The specimen is simply supported at its ends. As the velocity of striking body is changed, there must occur a transfer of energy; work is done on the parts receiving the blow. The mechanics of impact involves not only the question of stresses induced, but also a consideration of energy transfer and of energy absorption and dissipation.

The ability of material to absorbed energy and deform plastically before fracture is called "toughness". It is usually measured by the energy absorbed in a notched impact test like charpy or izod tests. In present work for each of the sample, test was conducted for 3times and the average of all the samples was taken as the observed values in each case.

3.10.1Machine specifications:- The specification of charpy machine used for the toughness test of present work is as follows.

Weight of hammer	18.75 kg
Striking of hammer	5 cm / s to 5.5 cm / s
Angle of hammer striking edge	30^0
Radius of curvature of striking edge	2 mm
Swing of hammer both ways	0 - 160^0

Fig. 9 Charpy impact tester for toughness testing.

CHAPTER 4

RESULTS AND DISCUSSION

The different kind of mild steel samples were carburized and tempered under the different condition and temperature and then tested for various kinds of test like abrasive wear test, tensile strength test, toughness test and hardness test. The results of abrasive wear test as received for different load (i.e.14.7 N, 29.4 N and 49 N) is recorded in Table 3 – 5, the result of Rockwell hardness test at 150 kg load is recorded in Table – 6. Similarly the result of toughness test and tensile strength test is recorded in Table – 7 and 8 respectively. The proximate analysis of Vasundhara coal is also done which is used as a carburized and its value is shown in Table – 2.

4.1 Results of proximate analysis of Vasundhara coal:-

The results of proximate analysis of vasundhara coal is shown in Table – 2, this analysis is performed to find out the percentage (wt %) of moisture, volatile matter, ash and carbon content in the given coal sample. From the analysis we found that vasundhara coal content 31% of carbon, 5% of moisture, 29% of volatile matter and 35% of ash.

4.2 Results of abrasive wear test:-The abrasion characteristics of carburized mild steels:

The results of abrasive wear test of carburized mild steels, carburized at different temperature of 850, 900 and 950^{0}C is shown in Table 3 – 5. The weight loss curve as a function of hardness for these steels is shown in Fig.22 – 25, roughly speaking, the weight loss during abrasion of all these carburized steels decreases linearly with the increase of hardness and carburization temperature. From the experimental results of abrasive wear test (Table 3 – 5), the following regularities can be found.

1. The weight loss during abrasion is highest for uncarburized simple mild steel and is lowest for the mild steel carburized at temperature of 950^{0}C.
2. As comparing the case of carburized mild only, the weight loss during abrasion is highest for the mild steel carburized at temperature of 850^{0}C and is lowest for the mild steel

carburized at temperature of 950^0C, that is because of comparatively low carbon content at lower carburization temperature. So it is concluded that, as the carburization temperature increases the weight loss during abrasion is decreases. This conclusion is also shown graphically in the Fig.10 – 13.

3. The abrasion test is conducted under three different loads of 14.7 N, 29.4 N and 49 N and it is obtained from the test that the weight loss during the abrasion is highest for the load of 49 N and is lowest for the load of 14.7 N. so it is concluded from the test that, as the load increases the weight loss during abrasion is also increases and this results is also shown graphically in the Fig.13.
4. The wear rate is highest for uncarburized simple mild steel and is lowest for the mild steel carburized at temperature of 950^0C and this wear rate is gradually decreases with increase in carburization temperature, these results shown graphically in Fig.14 – 17. this is due to the fact that the weight loss during abrasion is directly proportional to the wear rate, so as the carburization temperature increases the weight loss during abrasion decreases and simultaneously there is the decrease in the wear rate.
5. The wear rate is also load dependent and the abrasion test results shown that the wear rate increases gradually while increasing the applied load, so the wear rate is highest for the load of 49 N and it is lowest for the load of 14.7 N. This comparison shown graphically in the Fig.17.
6. The wear resistance is highest for the mild steel carburized at the temperature of 950^0C and it is lowest for the uncarburized mild steel. For taking the case of only carburized mild steels also the wear resistance is highest for the mild steel carburized at the temperature of 950^0C and is lowest for mild steels carburized at temperature of 850^0C. Hence the abrasion results explain that the wear resistance is directly proportional to the carburization temperature, as the carburization temperature increases the wear resistance increases. These results shown graphically in the Fig.18 – 21.
7. The net results is that the mild steel carburized at temperature of 950^0C giving the best results, as it has having the highest wear resistance, lowest weight loss due to abrasion and lowest wear rate.

4.3 Mechanical properties results (tensile strength, toughness and hardness test results):-

In general heat treatment and carburization of mild steels resulted in an increase in hardness, tensile strength and wear resistance and decreases the weight loss during abrasion and toughness values. The tests results of different mechanical characteristics like tensile strength, toughness and hardness under the different carburization temperature of 850, 900 and 950^{0}C is shown in Table 6 – 8 and summarized under the following points.

1. The tensile strength is varied between the ranges of 441MPa – 1960 MPa (Table – 8) and is highest for the mild steel carburized at temperature of 950^{0}C and lowest for the uncarburized simple mild steel. This results shows that the carburization greatly improved the tensile strength of mild steels.
2. For taking the case of carburized mild steels only, the tensile strength is highest for the mild steels carburized at the temperature of 950^{0}C and is lowest for the mild steels carburized at temperature of 850^{0}C, that's leads to the conclusion that with the increase in the carburization temperature, the tensile strength of carburized mild steels increases. This result is also shown graphically in the Fig.26.

3. From the results of the toughness test(Table – 7) it is analyses that the toughness is varied between the range of 54J – 32J and it is highest for the uncarburized mild steels and lowest for the mild steels carburized at temperature of 950^{0}C. So it is concluded that the carburization process decreases the toughness of the mild steels. This results is expected and it is also supported from the litrature[21]
4. It is also obtained from the toughness test results that. As the carburization temperature increases from value of 850 – 950^{0}C, there is a little decrease in the toughness values from 37J – 32 J, so it is concluded from the results that with increase of carburization temperature, the toughness values decreases.

5. The hardness values varied between range of 51 Rc – 57 Rc and it is highest for the mild steel carburized at temperature of 950^{0}C and is lowest for the mild steels carburized at

850^0C, so with increase of carburization temperature the hardness values increases. This is also shown graphically in the Fig.28. From the hardness test experiment it is also noted that the hardness values of uncarburized simple mild steel is unable to calculate in Rc scale because of its very less hardness values.

6. Finally the net results is that the mild steels carburized at 950^0C is giving the best results for the mechanical and wear properties like tensile strength, hardness and wear resistance except the case of toughness test.

4.4 Effect of carburization temperature on weight loss of carburized mild steels:-

The variation of carburization temperature with wait loss due to abrasion is shown in the Table 3 – 5 and it is also graphically represented in the Fig.10 – 13. From these results we found that the wait loss due to abrasion is highest for the mild steel carburized at temperature of 850^0C and it is lowest for the mild steel carburized at temperature of 950^0C. From the graph it is shown that the weight loss curve decreases gradually with increase in the carburization temperature. This result is expected because as the carburization temperature increases, the hardness of carburized mild steel is also increases and due to increase in the hardness the weight loss due to abrasion is decreases.

4.5 Effect of load on the weight loss of carburized mild steels:-

The abrasive wear test is conducted for the three different load of 14.7 N, 29.4 N and 49N for the carburized mild steels and the results is shown in the Table 3 – 5 and it is found that the weight loss due to abrasion is greatly affected with increase in applied load, the weight loss due to abrasion is highest for the load of 49 N and it is lowest for the load of 14.7 N. The result shows that, with the increase in the applied load the weight loss due to abrasion is also increases, this is because of the increase in the force, the friction increases which causes the weight loss. A graphically comparison of weight loss due to abrasion with the three different loads is also represented in the Fig.13. where it shows that weight loss due to abrasion is highest for the load curve of 49 N and it is above other two curve.

4.6 Effect of carburization temperature on wear resistance of carburized mild steels:-

The effect of carburization temperature on wear resistance of carburized mild steels for the three different temperatures of 850, 900 and 950^{0}C is shown in the Table 3 – 5 and it is plotted graphically in the Fig.18 – 21. where it is shown that wear resistance varies directly with the carburization temperature, it means with increase of carburization temperature the wear resistance also increases and the wear resistance is maximum for the mild steels carburized at temperature of 950^{0}C and it is minimum for the mild steels carburized at temperature of 850^{0}C. So the mild steels carburized at temperature of 950^{0}C is giving the best results and it is preferred.

4.7 Effect of hardness on the weight loss of carburized mild steels:-

The variation between hardness and weight loss due to abrasion is represented graphically in the Fig.22 – 25. Where it is found that the weight loss due to abrasion is highly influenced by the hardness and it varies inversely relationship with the hardness this means with increase in the hardness values of carburized mild steels the weight loss due to abrasion is decreases. Or in other words for the carburized mild steels having higher weight loss due to abrasion, its hardness must be less. That is because of the hard material having the greater abrasive wear resistance, so the less wear occurs in the carburized mild steels and the weight loss decreases.

4.8 Effect of carburization temperature on tensile strength of carburized mild steels:-

The effect of carburization temperature on tensile strength of carburized mild steels is shown in the Table – 8 and it is also represented graphically in the Fig.26. The results of tensile strength shows that the carburization process greatly improve the tensile strength of mild steels. The results explain that the tensile strength varied directly with the carburization temperature. This concluded that with the increase in the carburization temperature, the tensile strength increases linearly and comparing the carburization temperature of 850, 900 and 950^0C, the tensile strength is highest for the mild steel carburized at 950^0C, and lowest for 850^0C. So the mild steels carburized at 950^0C is giving the best results and it must be preferred.

4.9 Effect of carburization temperature on toughness of carburized mild steels:-

The toughness properties of mild steels is highly influenced by the carburization process the Table – 7 shows the toughness results of carburized and uncarburized mild steels where it is found that the toughness values of uncarburized mild steels is higher than that of carburized mild steels and toughness values decreases with increase in carburization temperature, so the process of carburization decreases the toughness of mild steels. This result is also shown graphically in the Fig.27. Which shows that with increase in the carburization temperature the toughness of carburized mild steels decreases. This results is also supported from the literature[21].

CHAPTER 5

CONCLUSION AND SUGGESTIONS FOR FUTURE WORK

5.1 Conclusions:-

From the present studies on “Mechanical and wear properties of carburized mild steels samples” the following conclusion have been drawn.

1. The mechanical and wear properties of mild steels were found to be strongly influenced by the process of carburization and carburizing temperature.
2. The carburization treatment followed by the water quenching appreciably improved the hardness, wear resistance and tensile strength of mild steels.
3. The carburization process decreases the toughness of the mild steels. And the toughness is decreases with increase in the carburization temperature.
4. The weight loss due abrasion, wear volume and wear rate increases with the increase in the applied load.
5. Hardness, wear resistance and tensile strength increases with increase in the carburization temperature.
6. Weight loss due to abrasion, wear volume, wear rate and toughness decreases with increase in the carburization temperature.
7. With increase in the hardness the wear resistance increases, but there is decrease in weight loss due to abrasion and wear rate.
8. As comparing for different carburization temperature. The mild steels carburized at the temperature of 950^0C shows the best combination of higher hardness, higher tensile strength and higher wear resistance with low weight loss and less wear rate.
9. Finally the net conclusion is that the mild steel carburized under the different temperature range of 850, 900, and 950^0C with in which the mild steel carburized at the temperature of 950^0C is giving the best results for the mechanical and wear properties like tensile strength, hardness and wear resistance.

5.2 Suggestions for the future work:-

After studying the Mechanical and wear properties of carburized steel sample under the different carburization temperature of 850, 900 and 950^{0}C. The following works are suggested to be carried out in the future.

1. The similar studies can be made for other types of wear like adhesive wear, erosive wear, corrosive wear etc.
2. The studies on abrasive wear can also be performed by varying its rotational speed and time.
3. The similar studies can also be made for other types of mechanical properties like elasticity, plasticity, compressive strength, ductility, brittleness and malleability etc.
4. The similar studies can be performed by changing the carburization temperature.
5. The similar studies can also be made by changing the soak time and the tempering temperature.
6. The similar studies can be performed for the heat treated medium carbon steels.
7. The similar studies can also be performed by changing its quenching medium.
8. The similar studies can also be performed for other type of heat treatment process like nitriding, cyaniding, carbonitriding etc.

Table – 2

Proximate analysis of Vasundhara coal

Coal	Proximate analysis (Wt %)			
	Moisture	Volatile matter	Ash	Fixed carbon
Vasundhara coal	5	29	35	31

Table – 3

Result of abrasive wear test for carburized mild steel, at load 14.7 N

Carburization condition		Tempering condition		Weight loss, g	Wear Volume $cm^3 x10^{-2}$	Wear rate, $cm^2 x10^{-7}$	Wear resistance, $cm^{-2} x10^7$
Temp (^0C)	Soak time(Hrs)	Temp(^0C)	Soak time (Hrs)				
Simple mild steel	_	_	_	0.210	2.67	3.92	0.255
850^0C	2	200^0C	0.5	0.133	1.69	2.48	0.403
900^0C	2	200^0C	0.5	0.118	1.5	2.20	0.455
950^0C	2	200^0C	0.5	0.109	1.38	2.02	0.495

Table – 4

Result of abrasive wear test for carburized mild steel, at load 29.4 N

Carburization condition		Tempering condition		Weight loss, g	Wear volume, cm^3x10^{-2}	Wear rate, cm^2x10^{-7}	Wear resistance $cm^{-2}x10^{7}$
Temp (^0C)	Soak time(Hrs)	Temp(^0C)	Soak time (Hrs)				
Simple mild steel	_	_	_	0.253	3.21	4.71	0.212
850^0C	2	200^0C	0.5	0.158	2.00	2.93	0.314
900^0C	2	200^0C	0.5	0.138	1.75	2.57	0.389
950^0C	2	200^0C	0.5	0.125	1.59	2.33	0.429

Table – 5

Result of abrasive wear test for carburized mild steel, at load 49 N

Carburization condition		Tempering condition		Weight loss, g	Wear volume, $cm^3 x10^{-2}$	Wear rate, $cm^2 x10^{-7}$	Wear resistance, $cm^{-2} x10^{7}$
Temp (^0C)	Soak time(Hrs)	Temp(^0C)	Soak time (Hrs)				
Simple mild steel	–	–	–	0.308	3.91	5.74	0.174
850^{0}C	2	200^{0}C	0.5	0.190	2.41	3.53	0.283
900^{0}C	2	200^{0}C	0.5	0.168	2.13	3.12	0.320
950^{0}C	2	200^{0}C	0.5	0.151	1.92	2.81	0.355

Table – 6

Rockwell hardness of carburized mild steel, at load 150 kg

Carburization condition		Tempering condition		Hardness(R_c)
Temp (^0C)	Soak time(Hrs)	Temp(^0C)	Soak time (Hrs)	
Simple mild steel	–	–	–	–
850^0C	2	200^0C	0.5	51
900^0C	2	200^0C	0.5	55
950^0C	2	200^0C	0.5	57

Table – 7

Result of toughness test of carburized mild steel

Carburization condition		Tempering condition		Toughness , Joule(Nm)
Temp (^{0}C)	Soak time(Hrs)	Temp(^{0}C)	Soak time (Hrs)	
Simple mild steel	–	–	–	54
850^{0}C	2	200^{0}C	0.5	37
900^{0}C	2	200^{0}C	0.5	35
950^{0}C	2	200^{0}C	0.5	32

Table – 8

Tensile strength of carburized mild steel

Carburization condition		Tempering condition		Tensile strength(mpa)
Temp (^{0}C)	Soak time(Hrs)	Temp(^{0}C)	Soak time (Hrs)	
Simple mild steel	–	–	–	441
850^{0}C	2	200^{0}C	0.5	1872
900^{0}C	2	200^{0}C	0.5	1925
950^{0}C	2	200^{0}C	0.5	1960

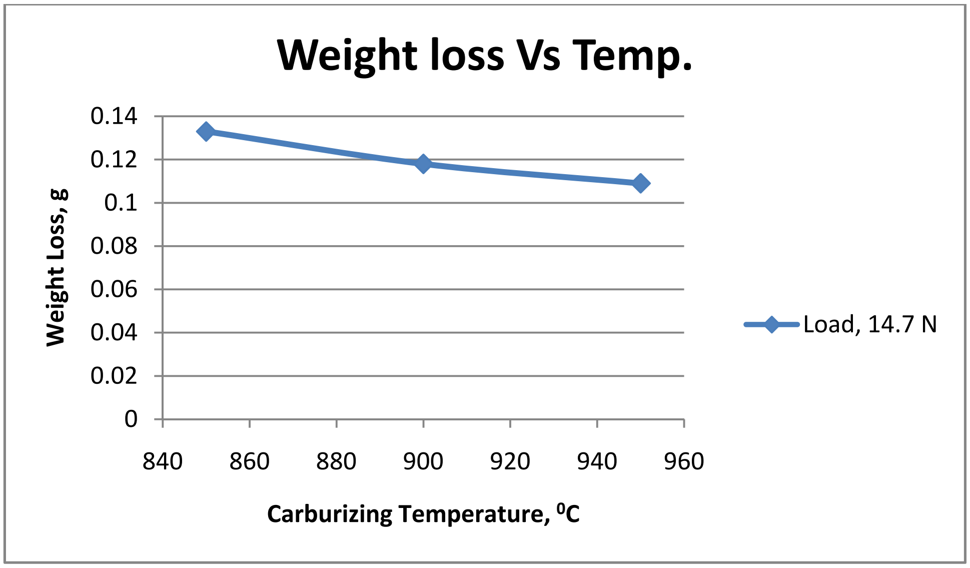

Fig. 10 Weight loss due to abrasion VS carburization temperature, at load 14.7 N

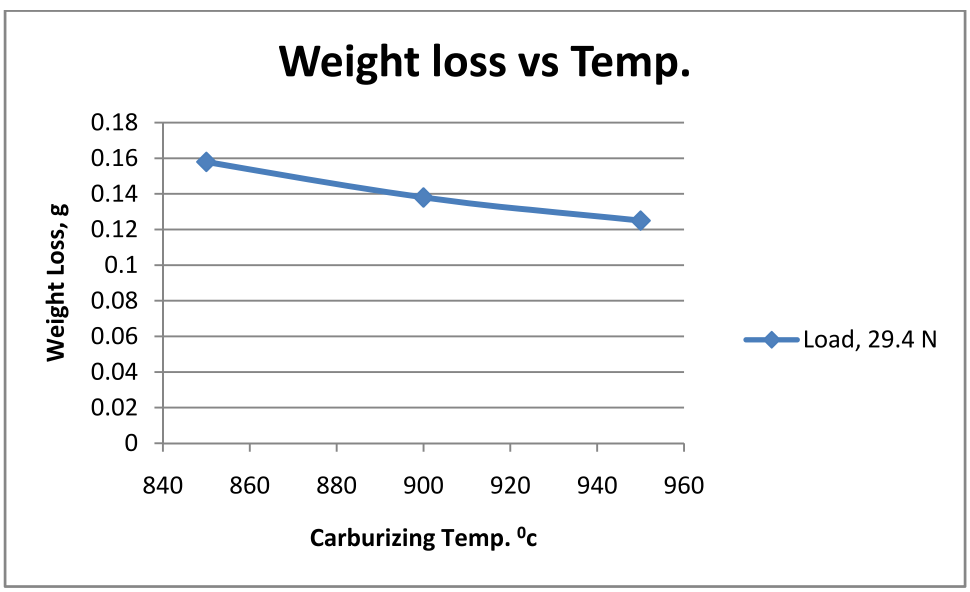

Fig. 11 weight loss due to abrasion VS carburization temperature, at load 29.4 N

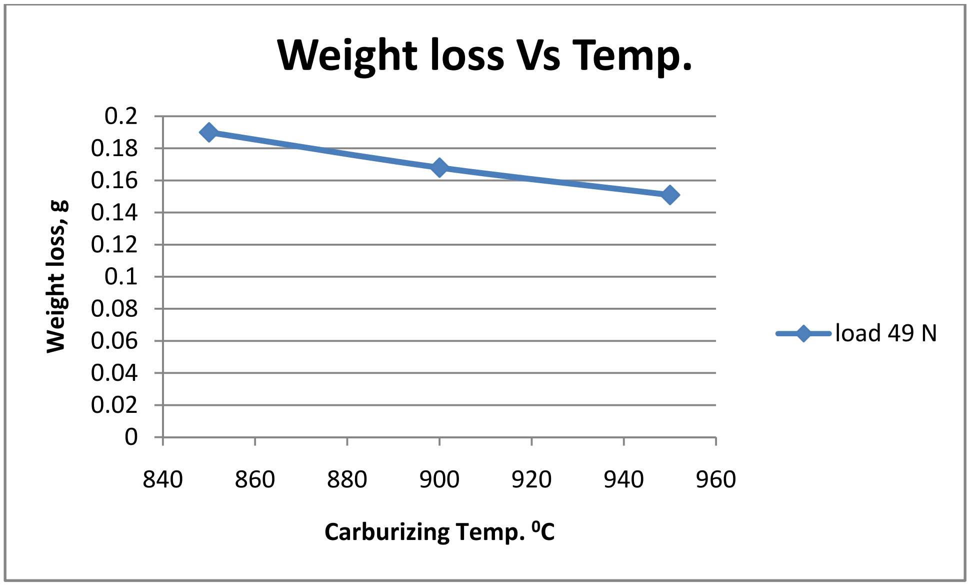

Fig. 12 weight loss due to abrasion VS carburization temperature, at load 49 N

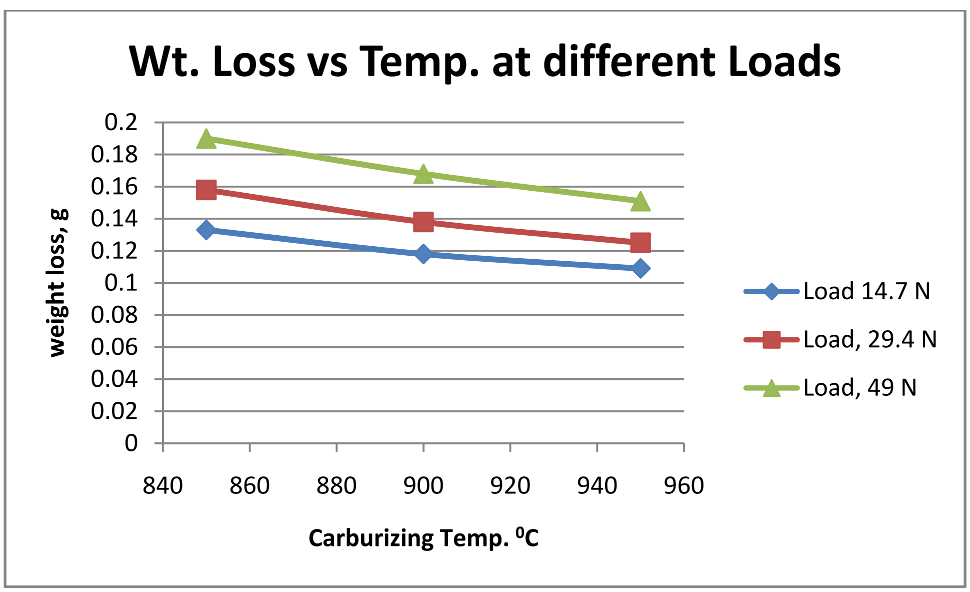

Fig. 13 Comparison of weight loss due to abrasion VS carburization temperature for three different loads of 14.7 N, 29.4 N and 49 N

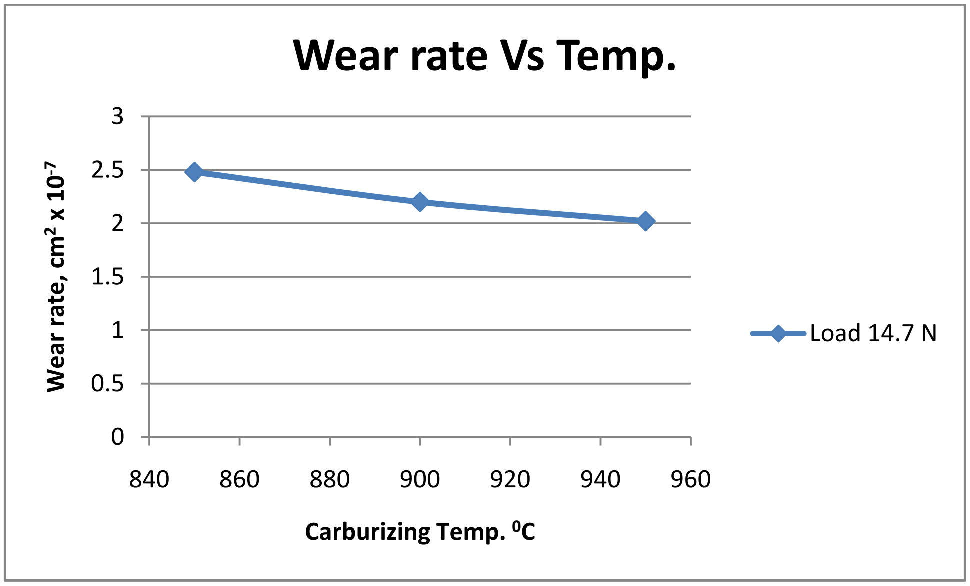

Fig. 14 Wear rate VS carburization temperature, at load 14.7 N

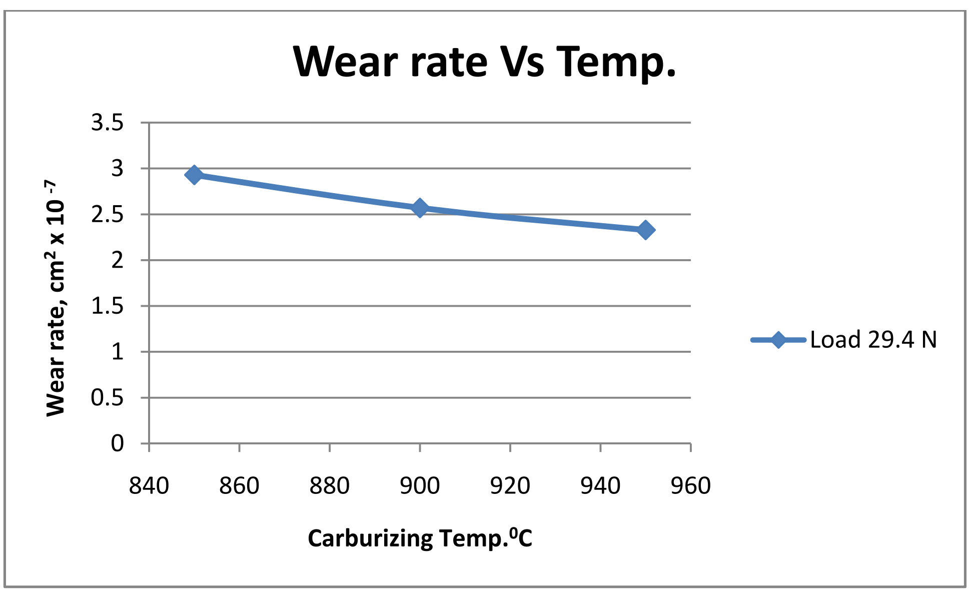

Fig. 15 Wear rate VS carburization temperature, at load 29.4 N

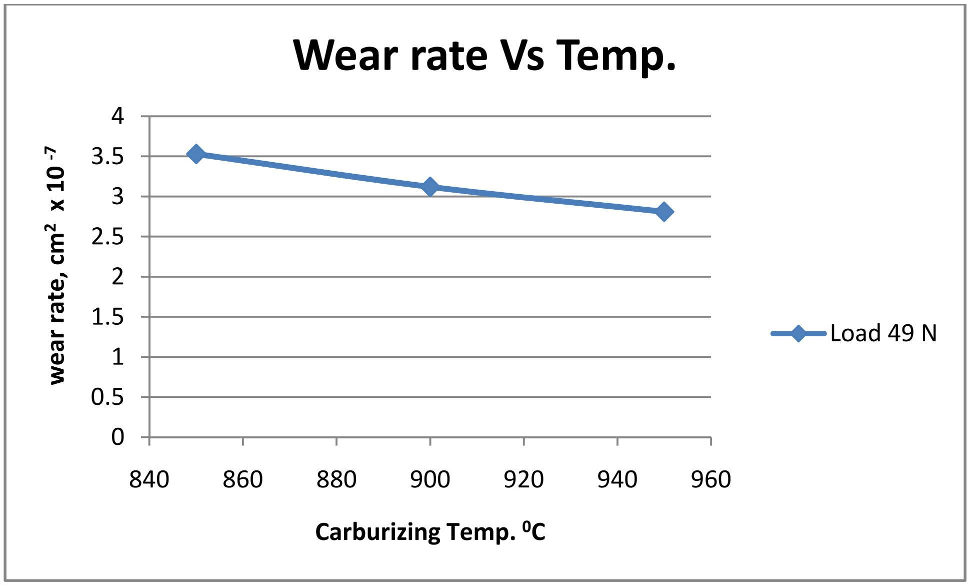

Fig. 16 Wear rate VS carburization temperature, at load 49 N

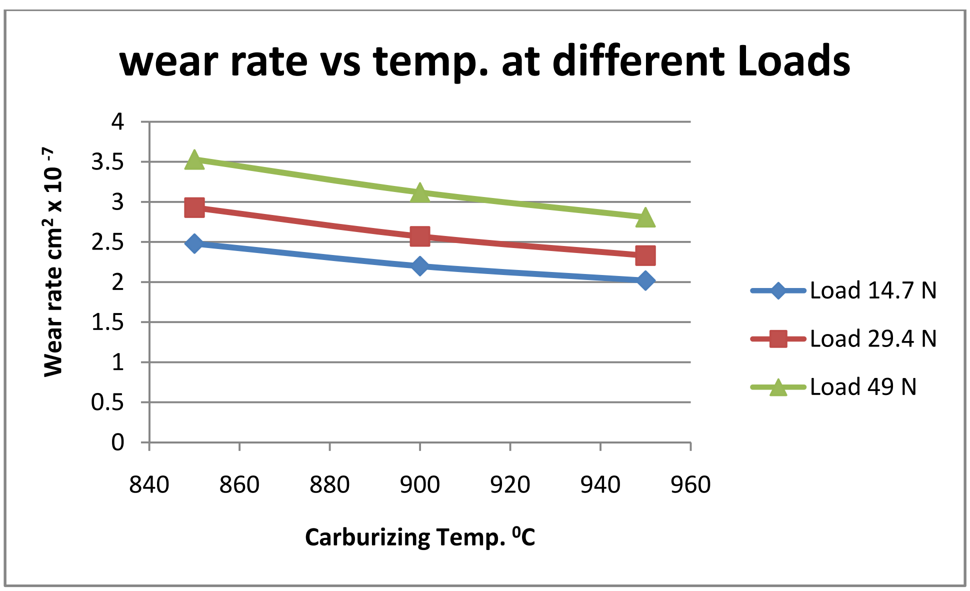

Fig. 17 a comparison of wear rate VS carburization temperature for three loads of 14.7 N, 29.4 N and 49 N

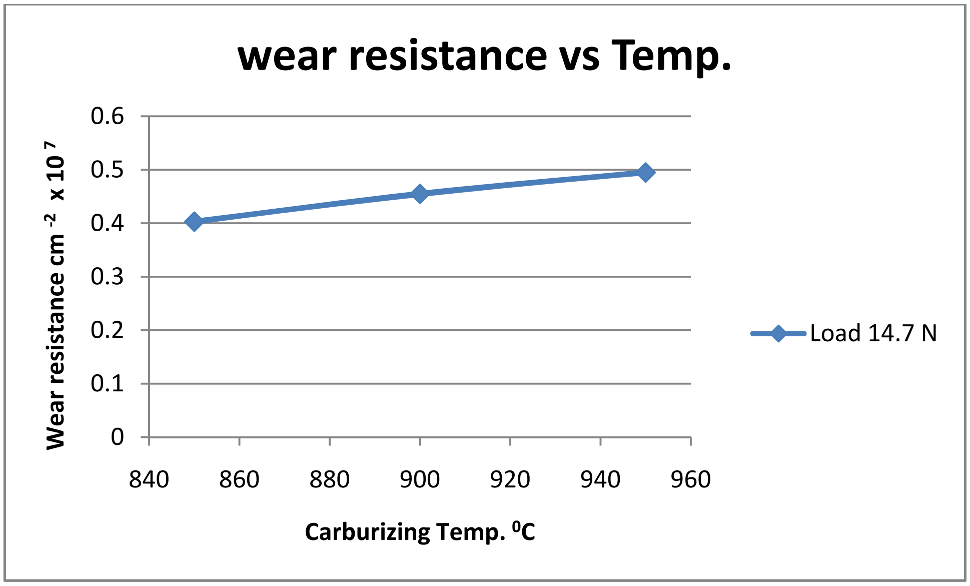

Fig. 18 Wear resistance VS carburization temperature, at load 14.7 N

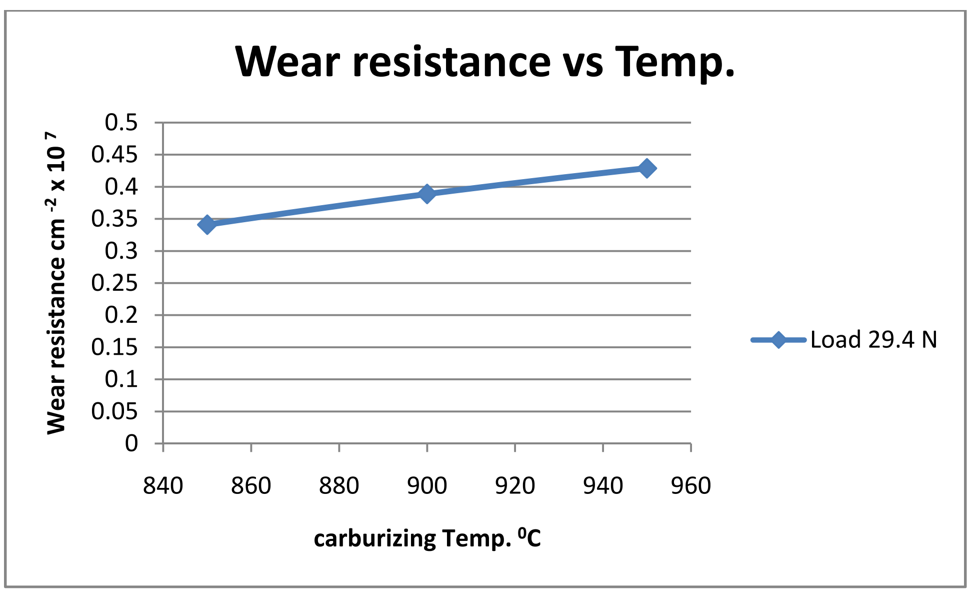

Fig. 19 Wear resistance VS carburization temperature, at load 29.4 N

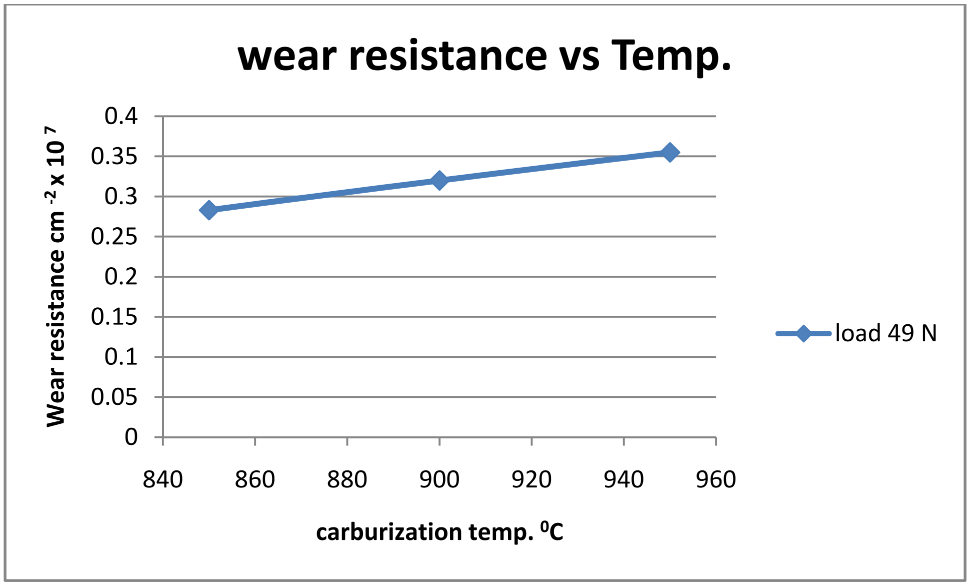

Fig. 20 Wear resistance VS carburization temperature, at load 49 N

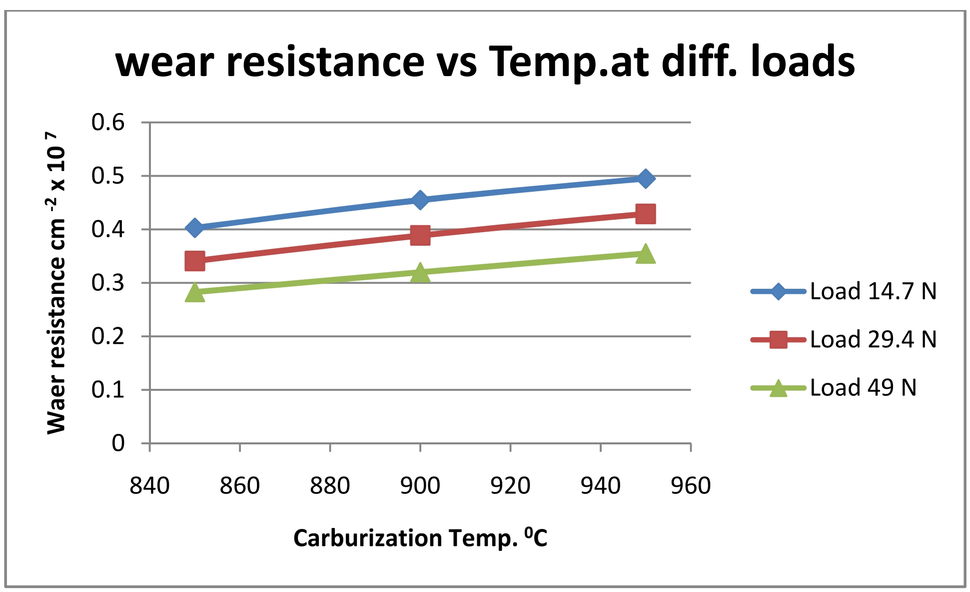

Fig. 21 a comparison between wear resistances VS carburization temperature for the three different loads of 14.7 N, 29.4 N and 49 N

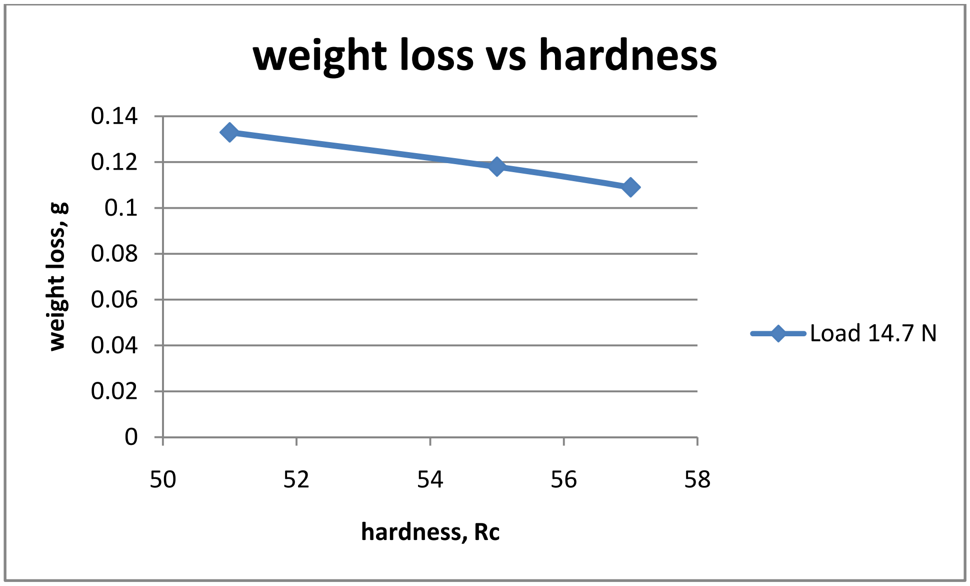

Fig. 22 Weight loss due to abrasion VS hardness, at load 14.7 N

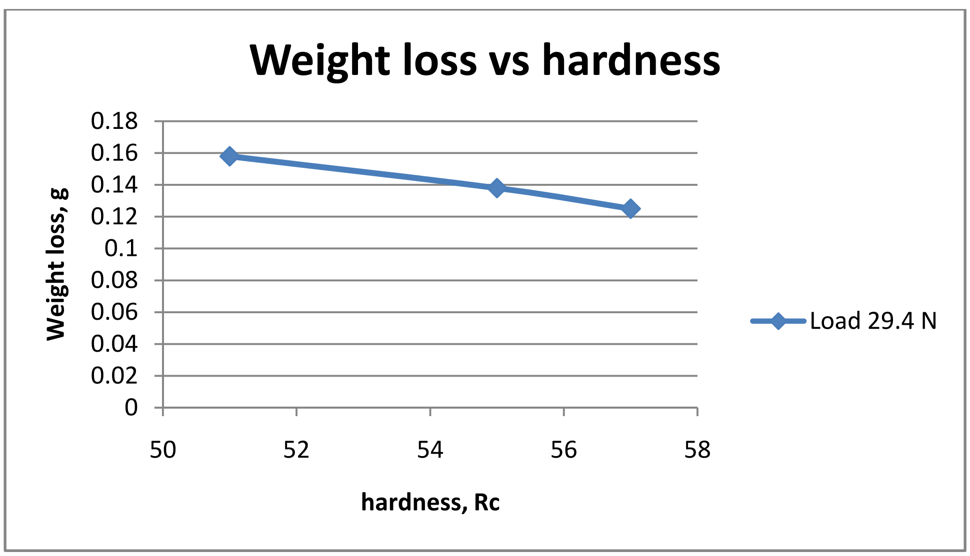

Fig. 23 weight loss due to abrasion VS hardness, at load 29.4 N

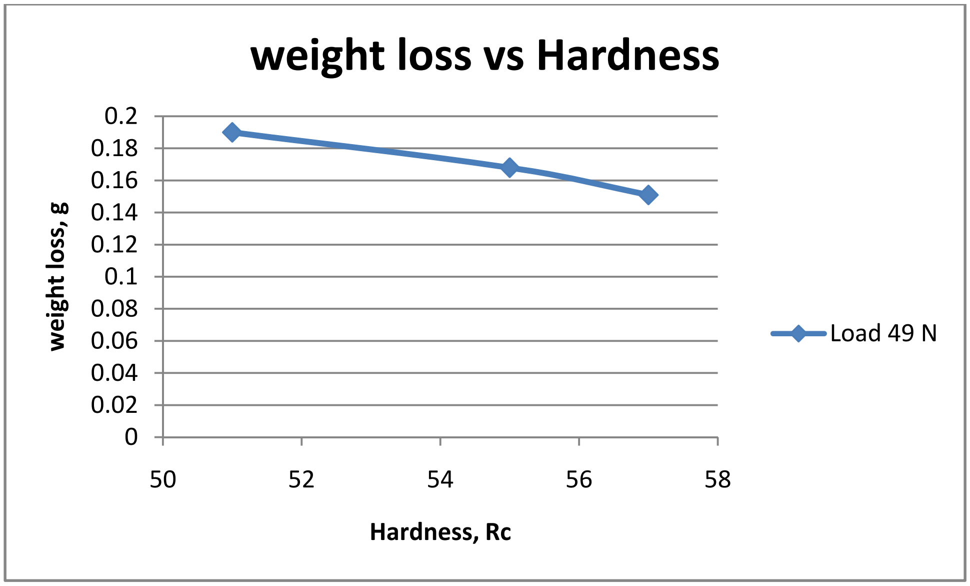

Fig. 24 weight loss due to abrasion VS hardness, at load 49 N

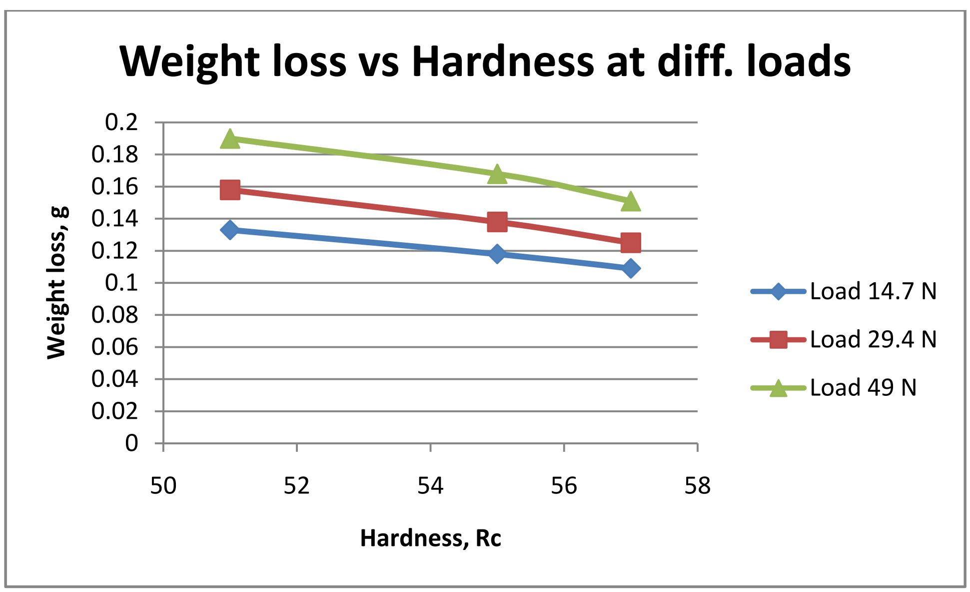

Fig. 25 a comparison of weight loss due to abrasion VS hardness for the three

Different loads of 14.7 N, 29.4 N and 49 N

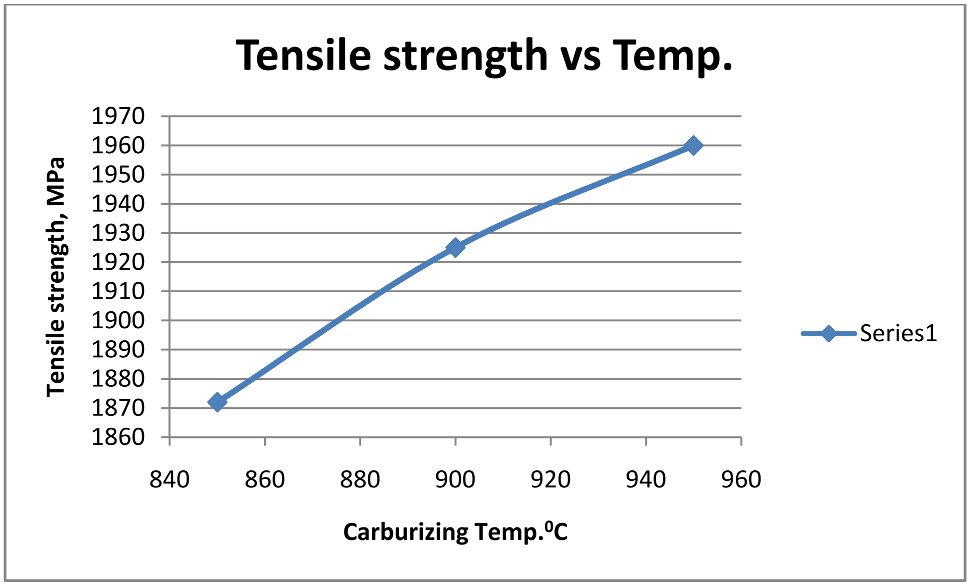

Fig. 26 Variation of tensile strength with carburization temperature

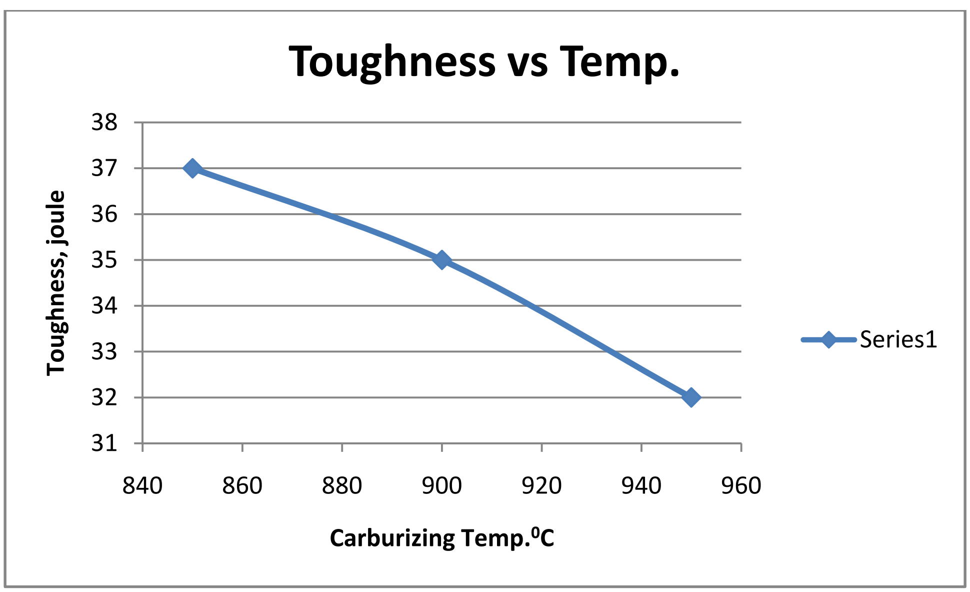

Fig. 27 Variation of toughness with carburization temperature

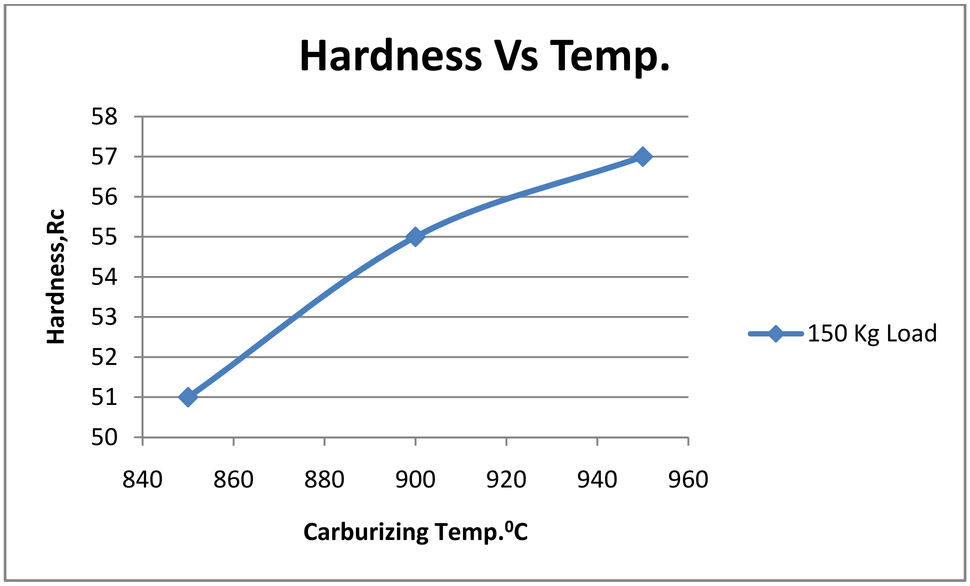

Fig. 28 Variation of hardness with the carburization temperature

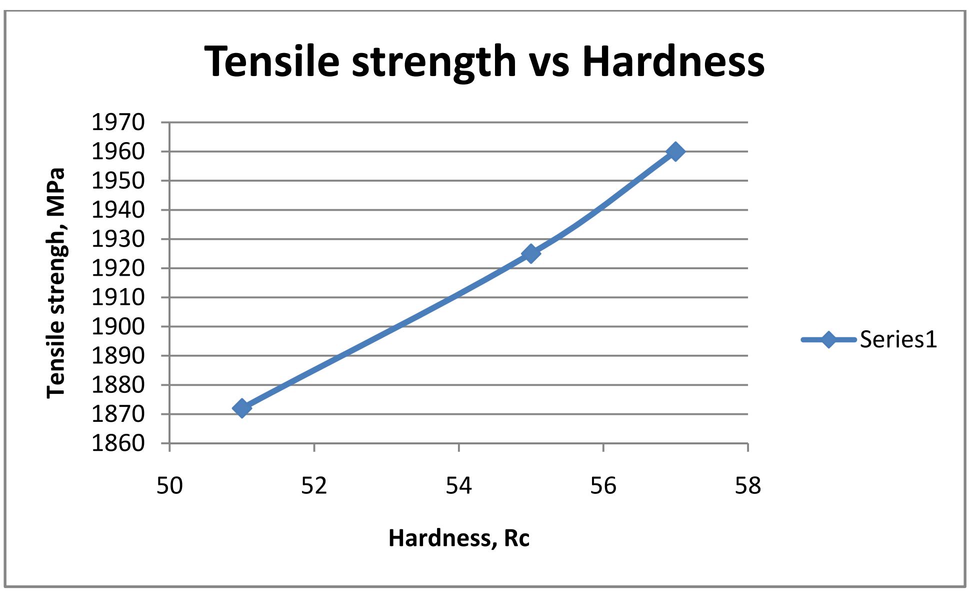

Fig. 29 Variation of tensile strength with hardness for the common Carburization temperature of 850, 900 and 950^{0}C

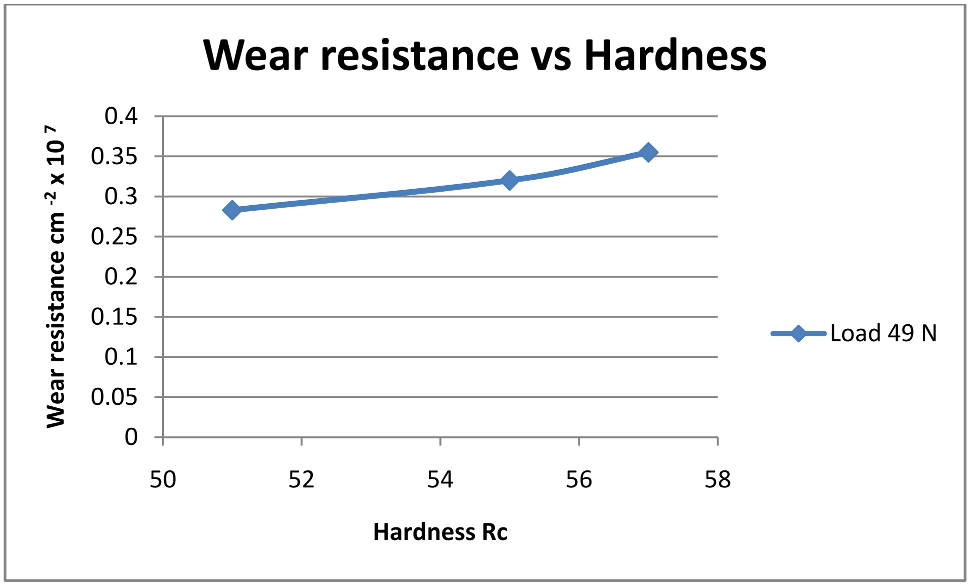

Fig. 30 Variation of wear resistance with hardness for the common carburization Temperature of 850, 900 and 950^{0}C

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